NISTIR 6527

Measurement Needs for Fire Safety: Proceedings of an International Workshop

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National Institute of Standards and Technology
Technology Administration, U.S. Department of Commerce

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U.S. Department of Commerce
William M. Daley, Secretary

Technology Administration
Dr. Cheryl L. Shavers, Under Secretary of Commerce for Technology

National Institute of Standards and Technology
Raymond G. Kammer, Director

Ktech CORP.

Fire Test Furnace Characterization Unit

U. S. Coast Guard R & D Center

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Workshop - Measurement Needs for Fire Safety

National Institute for Standards and Technology

April 3-7, 2000

Ned Keltner - Ktech Corporation

project officer: Louis Nash - U. S. Coast Guard

program manager: Jesse Beitel - Hughes Associates

Fire Safety Science & Standardized Tests

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- Overall, fire safety science is making significant advances
  - Modeling - physical phenomena, zone models, field models
  - Test methods - harmonizing national standards
  - Measurements - small & intermediate scale tests
- Unfortunately, progress on large furnace tests has been slow
  - Current efforts to improve measurement & control techniques
  - Current efforts to measure heat transfer in furnaces
- U. S. Coast Guard sponsored work has two main goals
  - Characterize thermal exposure in furnaces with a representative device
  - Use the results as an aid to harmonizing exposure in different furnaces

The Problem with Fire Safety Test Furnaces

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- U. S. Coast Guard fire safety test results vary significantly
  - Different furnaces produce different temperature histories (100°C or more at a given time) and different heat flux levels (up to 2X)
- Large variations are due to a number of factors including
  - Furnace size and lining
  - Furnace control thermocouple design, size, and installation
  - Fuel type (natural gas, propane, or fuel oil)
  - Test specimen properties
- A number of the causes have been studied and documented
  - Does the implicit assumption of q • •• •T^4 work in furnace tests?
  - Analysis & Comparison of Marine Fire Testing Regulations & Procedures N. A. Wittasek - MS Thesis - Worcester Polytechnic Institute - 1996

Installation & Temperature Measurement Uncertainty ISO 834 Furnace Control Thermocouple Assemblies:

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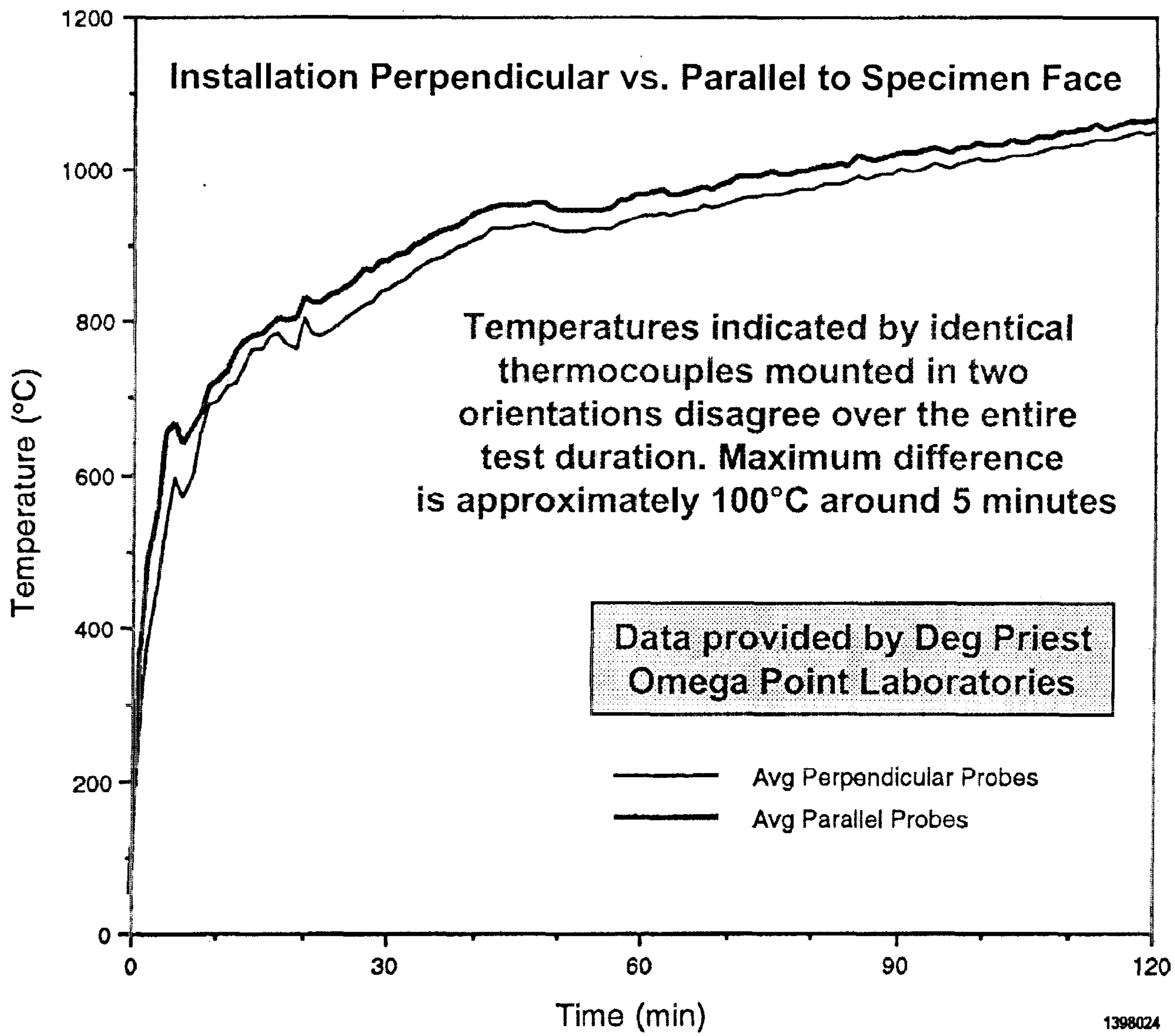

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Parallel vs Perpendicular ISO Furnace Probes

Radiant heat flux estimates vary with indicated temperature

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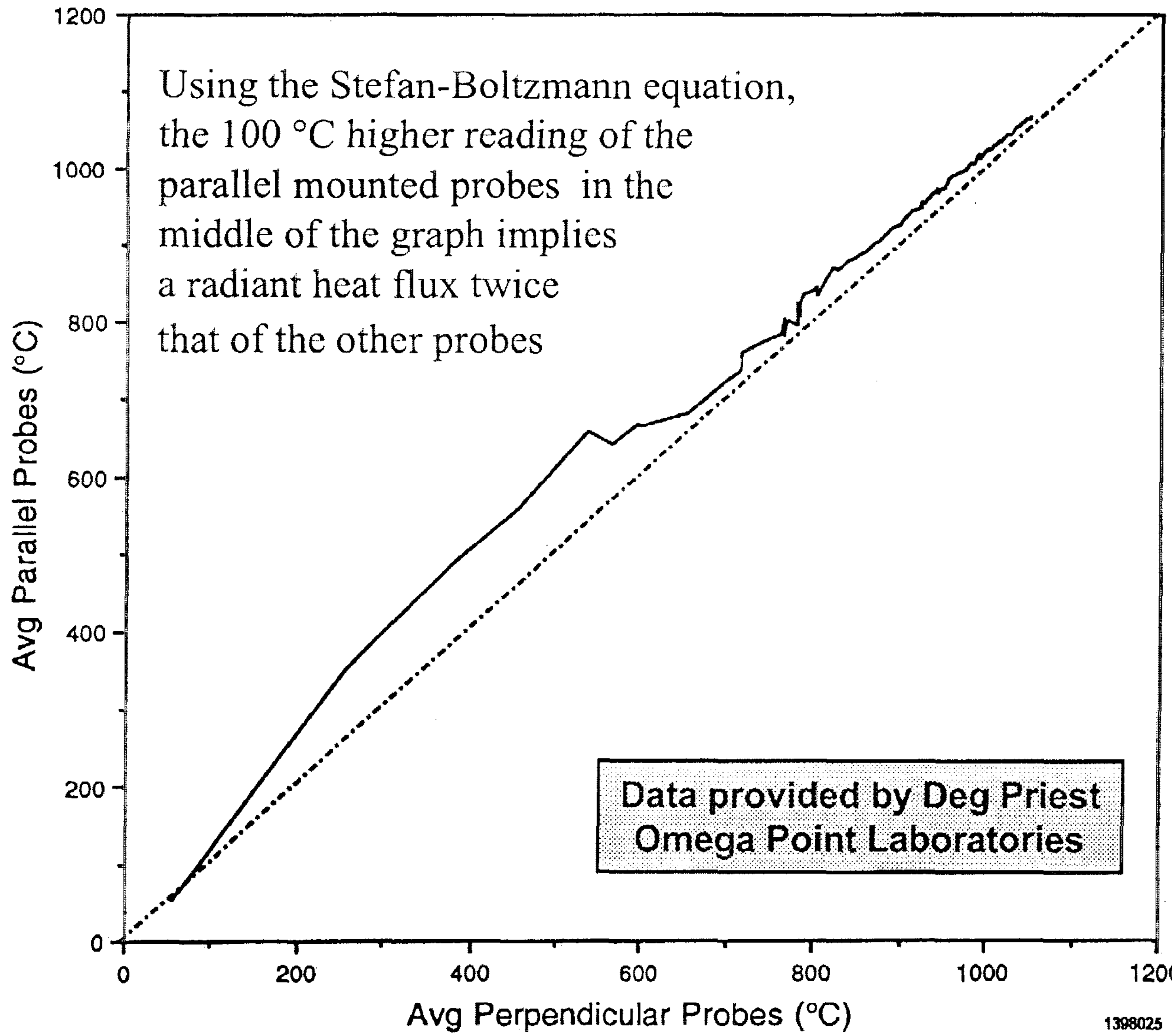

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What Does & Doesn't a Thermocouple Measure?

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- **Furnace temperature measurements re-emphasize well-known but often-forgotten points:**
  - A thermocouple can only measure its own temperature
  - *Measured thermocouple temperature* is related to but is not the same as the *temperature of the process* in which you are interested
- Measurements using conventional thermocouple designs
  - Indication is the result of an energy balance
  - Provide insufficient information for calculating heat flux
- Measurements using directional flame thermometers (DFT)
  - Double sided design enables an energy balance
  - Transient (calorimetric) & steady (effective radiation temperature) data

Furnace Characterization System Design

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- U. S. Coast Guard R & D Center - initiated development of a system for characterizing temperatures and heat fluxes in fire safety test furnaces
- Design is an integrated measurement - acquisition - analysis package
  - Large size (1 m x 1m) with a multi-point sensor array
  - Digital data acquisition system & portable computer
  - Utilizes nonlinear parameter estimation and inverse heat conduction codes
- Features
  - All metal construction with thermal inertia similar to a marine bulkhead
  - High temperature capability — heated surface up to 1000°C
  - Redundant measurements of heat transfer
  - Uses both standard thermocouples and directional flame thermometers

Furnace Characterization Unit Layout

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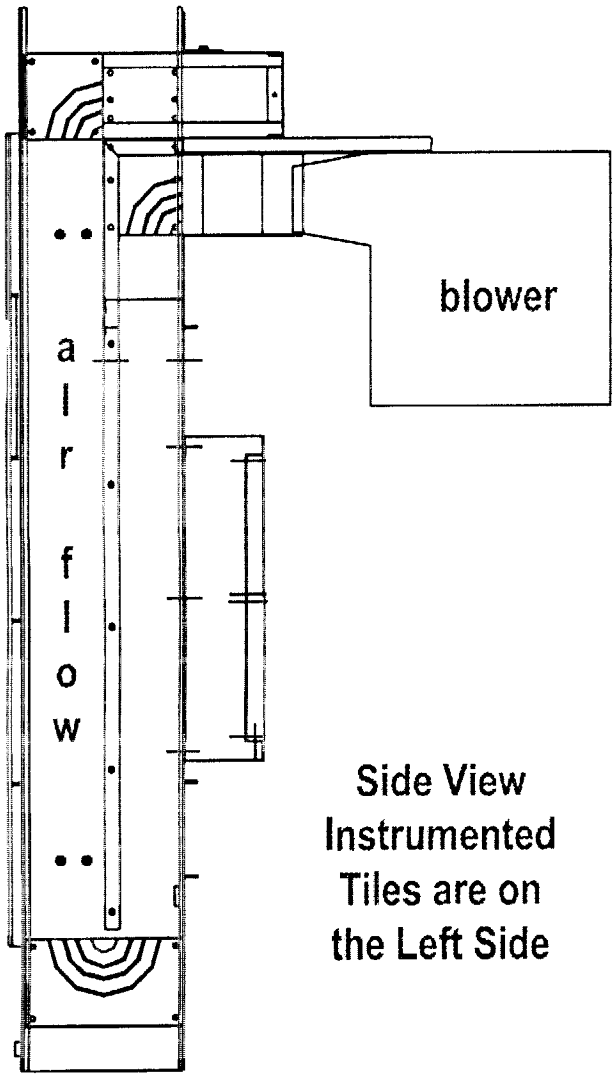
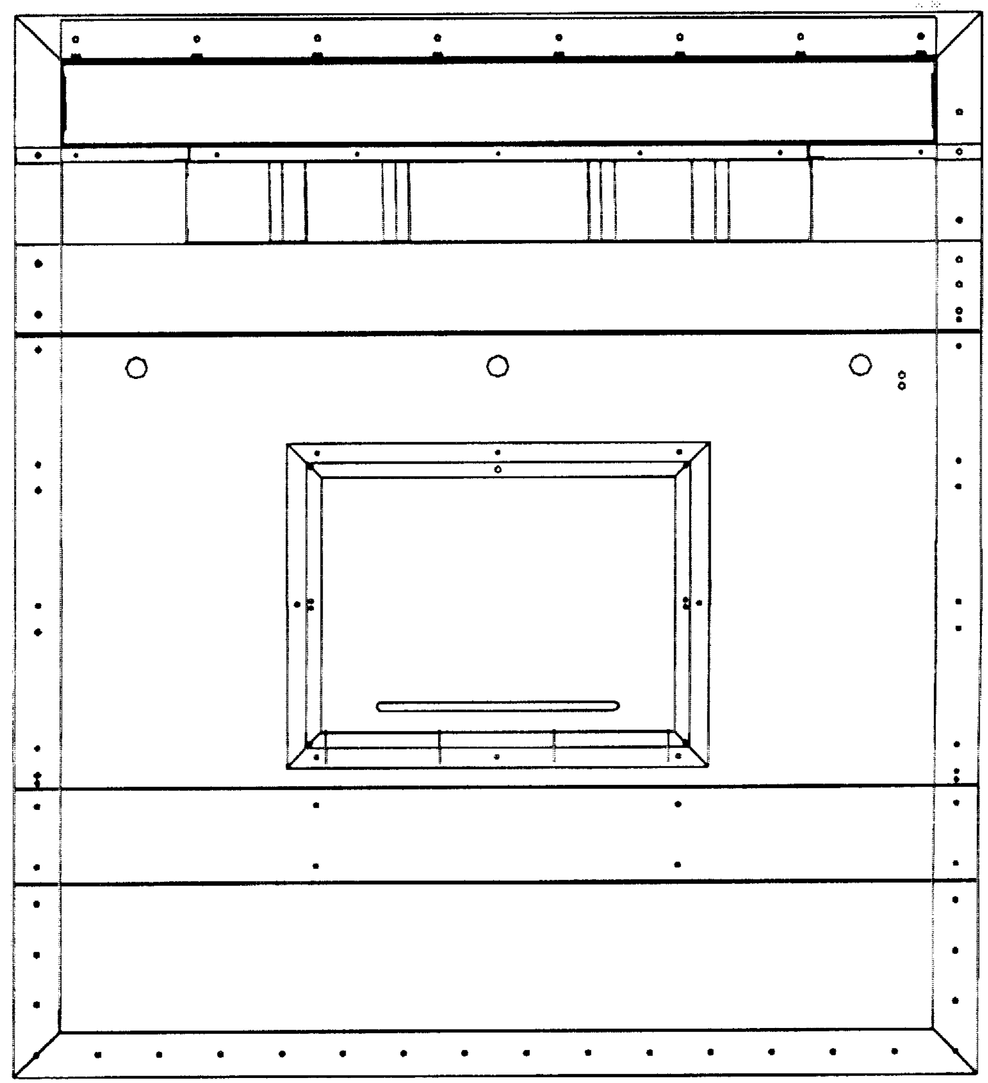


Side View
Instrumented
Tiles are on
the Left Side



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Exposed Surface of the Furnace Characterization Unit

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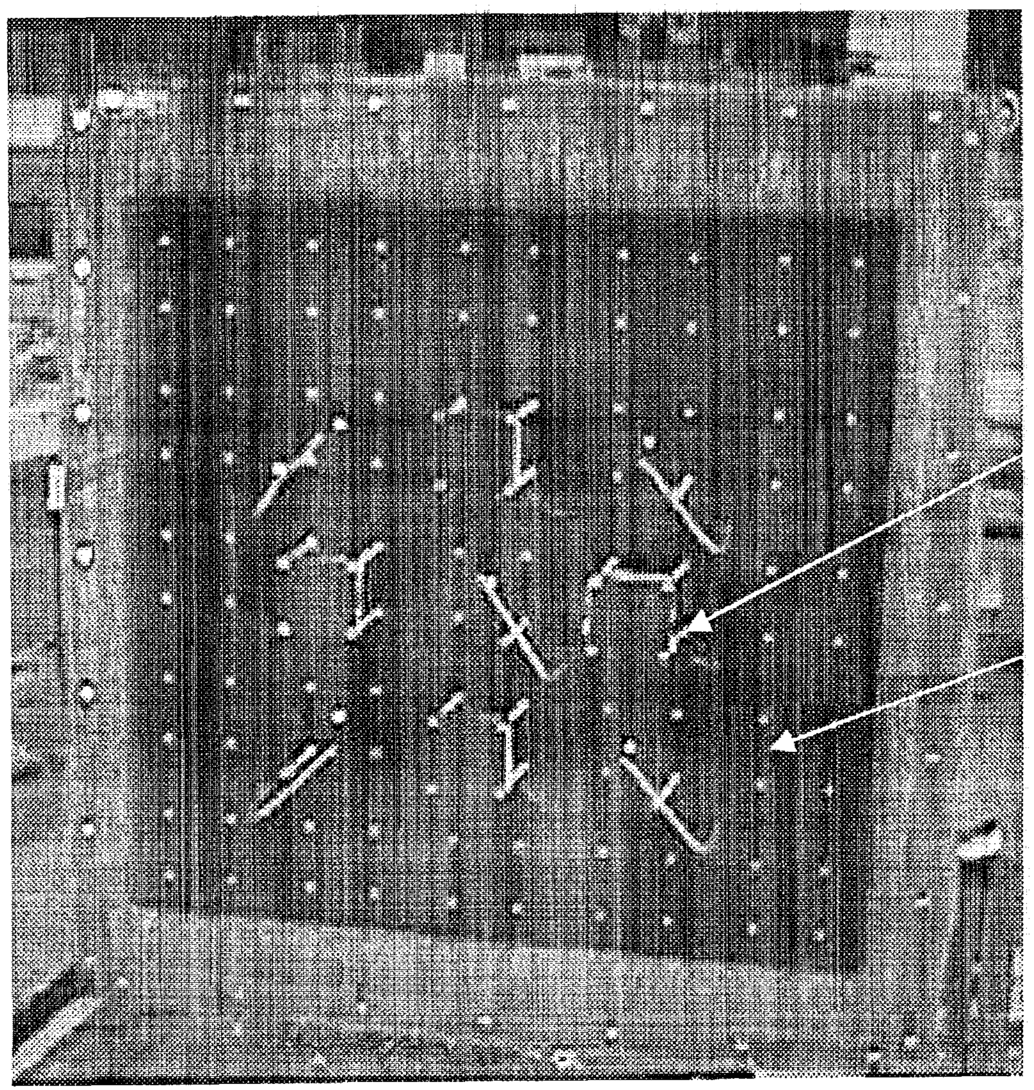

Directional Flame Thermometers

Inconel Tiles

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Design Issue Tests - Four Tile Instrumented Array

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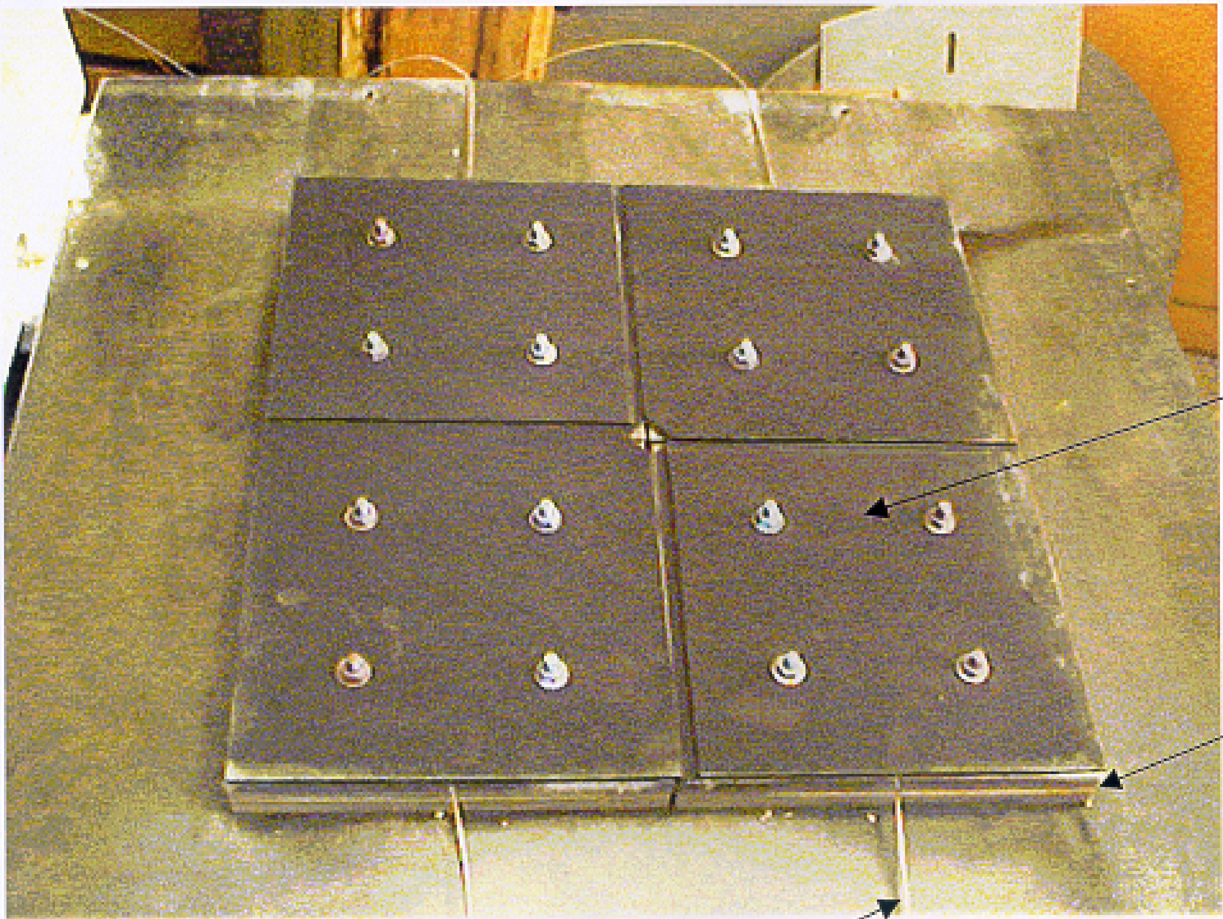

Inconel
Front Plate

Hastelloy–X
Metal Felt
Insulation
Layer

Thermocouple

Simplified Thermal Model Used for Interpreting Test Data

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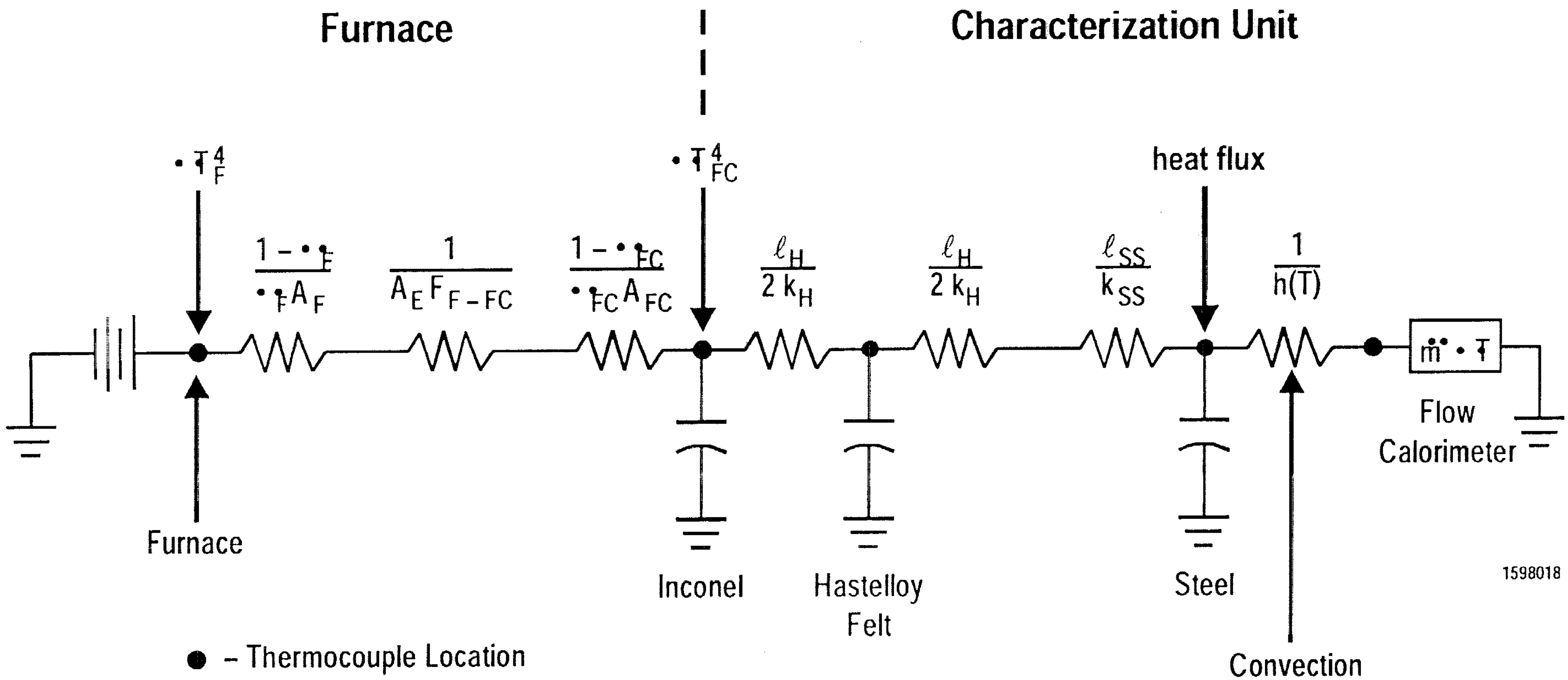

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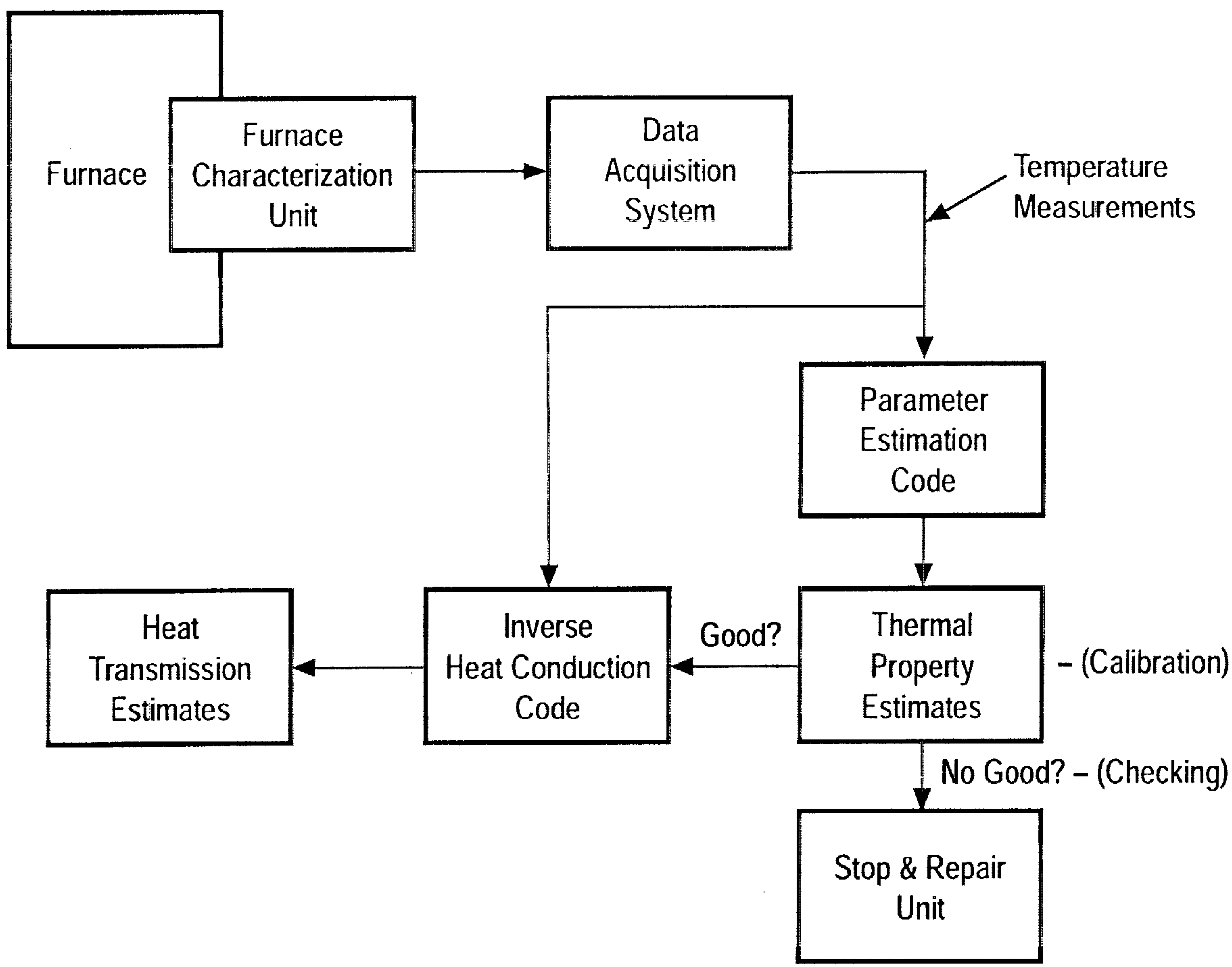
Furnace Characterization Unit Data Flow



Numerical Techniques for Estimating Thermal Properties and Heat Transfer Rates

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- **Parameter Estimation Code - (nonlinear - i.e., temperature dependent)**
  - Multi-Layer Materials
    - If some material properties are known - calculate properties of unknown layers
    - Assumed the properties of Inconel 600, volumetric heat capacity of Hastelloy-X metal felt, and Steel Backface were known
  - Estimated Thermal Conductivity (values incorporate as-built variations)
    - Hastelloy X Metal Felt vs temperature and stainless steel wool
    - Used measured temperatures of Inconel, mid-plane of the Hastelloy-X, plus temperature and heat flux on Steel
- **Nonlinear Direct & Inverse Heat Conduction**
  - Direct Mode - Interior Temperatures for Defined Boundary Conditions
    - Most thermal analysis codes operate in this mode
  - Inverse Mode - Surface Heat Fluxes or Surface Heat Transfer Coefficients
    - Uses interior temperature histories with thermal properties estimated above

Design Issue Test Data 8-13-97

Showed good agreement between four tiles

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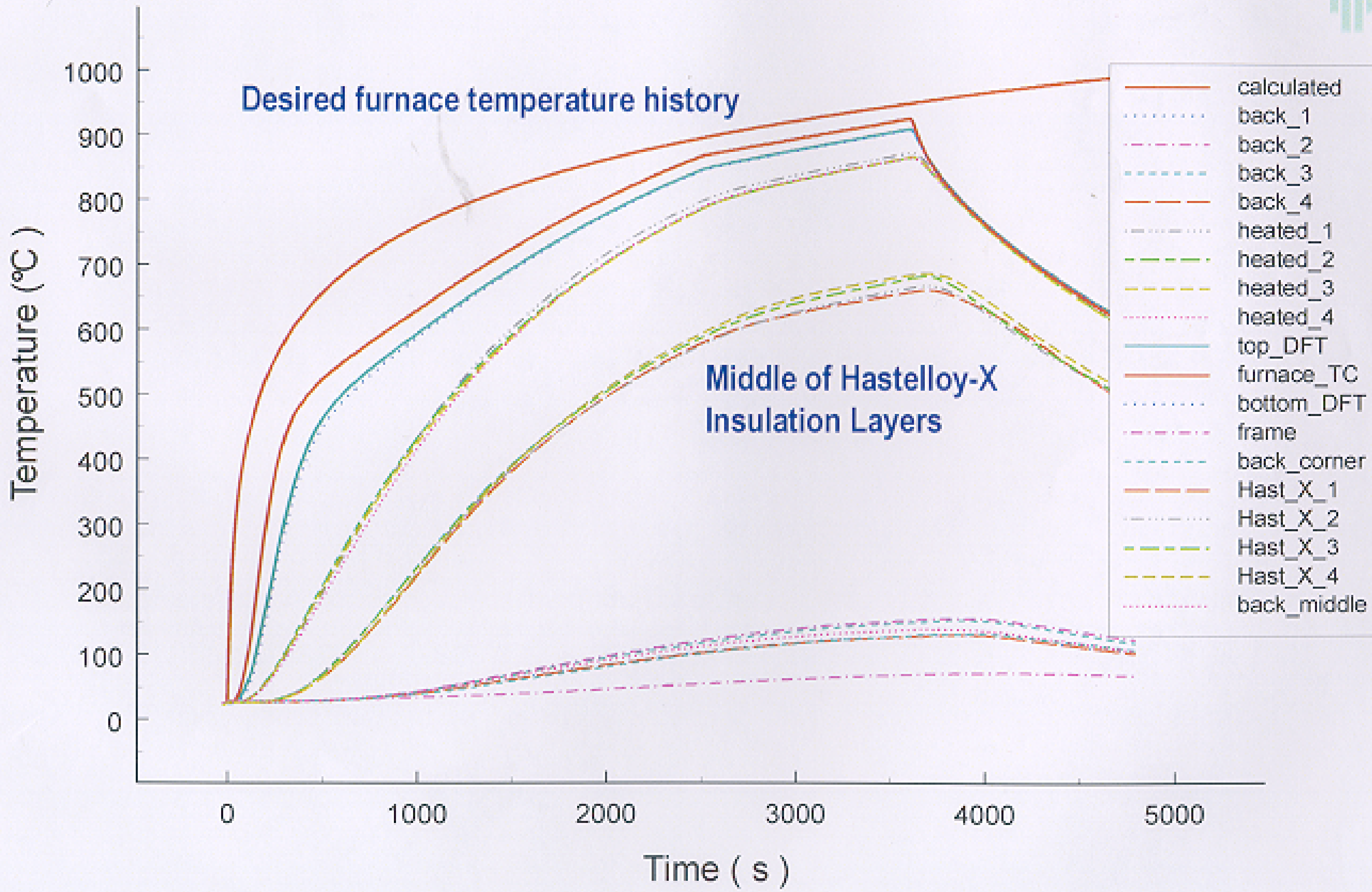

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Simplified & Inverse Analyses of Data

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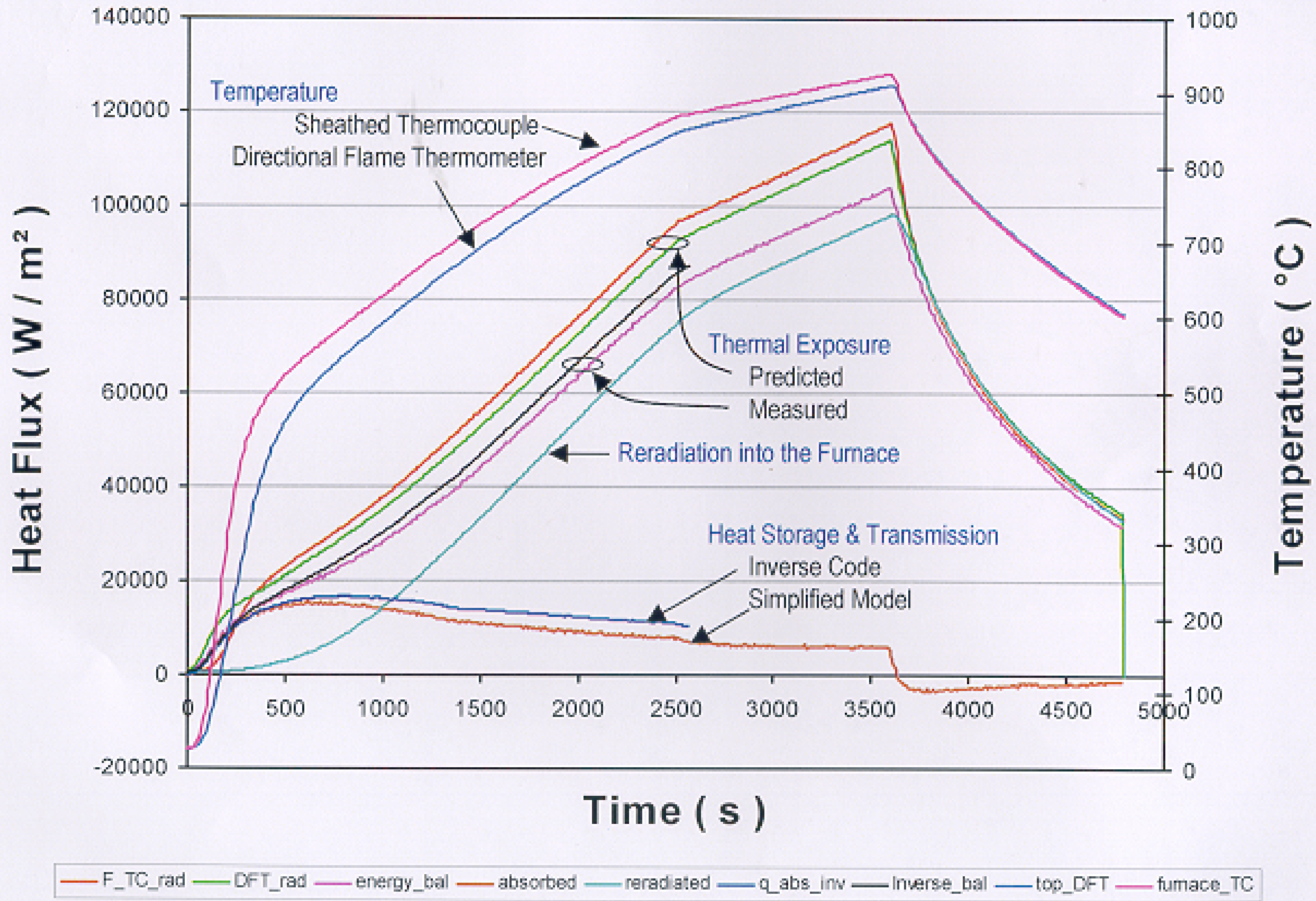

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FCU Calibration Tests

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- Calibration Tests were run at Sandia National Laboratories
  - Tests used the Dial-a-Fire Fixture - a fast, programmable electric furnace
  - All six surfaces of the test enclosure were instrumented
  - Three tests followed the logarithmic time-temperature curve specified in International Maritime Organization Regulation A754
  - Three tests followed a stair-step time-temperature profile
- Heat Fluxes from the Logarithmic Curves
  - Peak absorbed heat fluxes were 20 - 25 kW / m^2
  - Peaks occurred at approximately 15 minutes
  - Repeatability in peak values between 3 tests - 3%
- Radiosity Analysis
  - Accurately predicted DFT temperatures (within 1%)

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FCU Calibration Setup - Dial-a-Fire Heater Shroud

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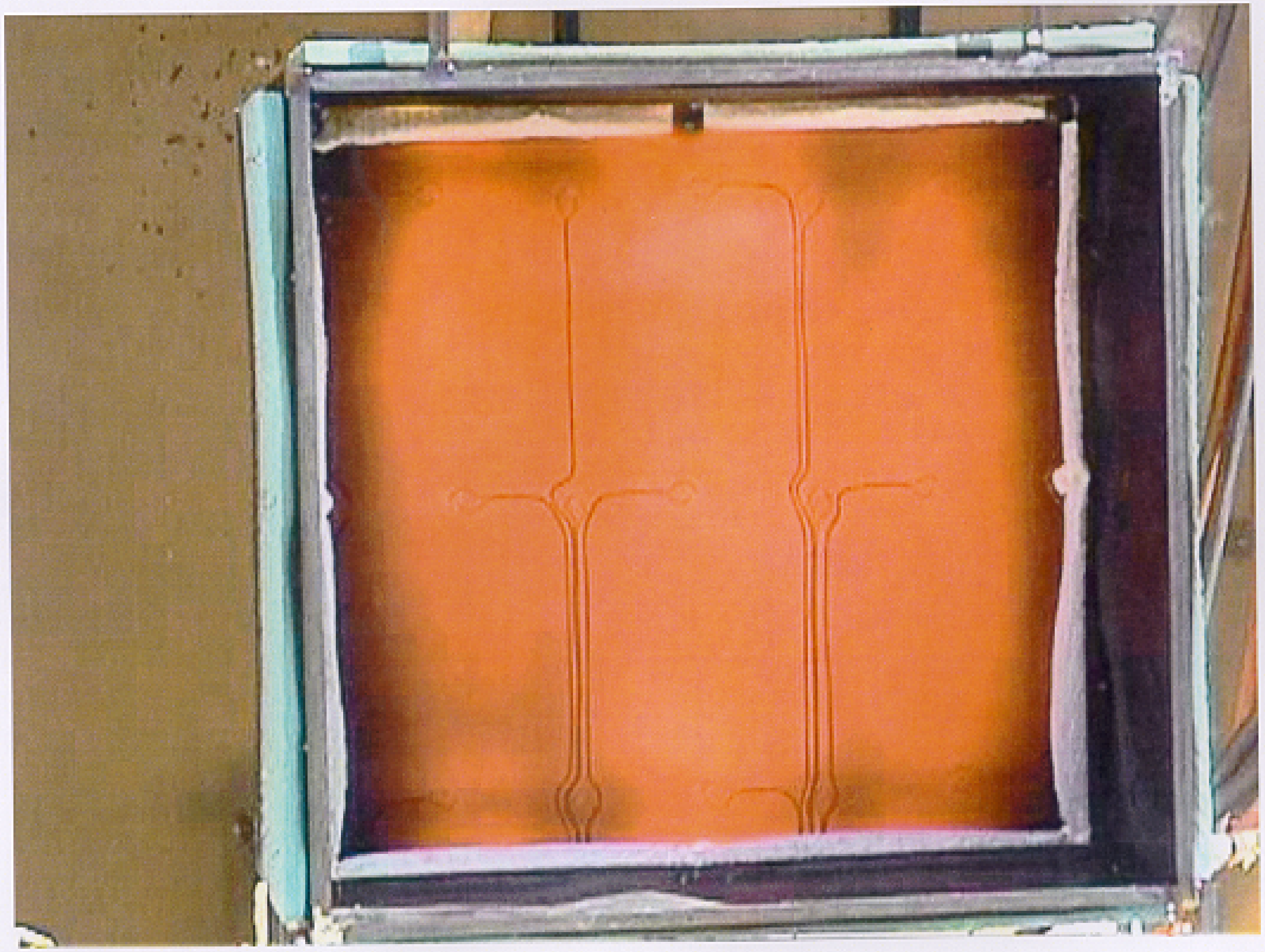

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Calibration Results - Logarithmic Time-Temperature Curve

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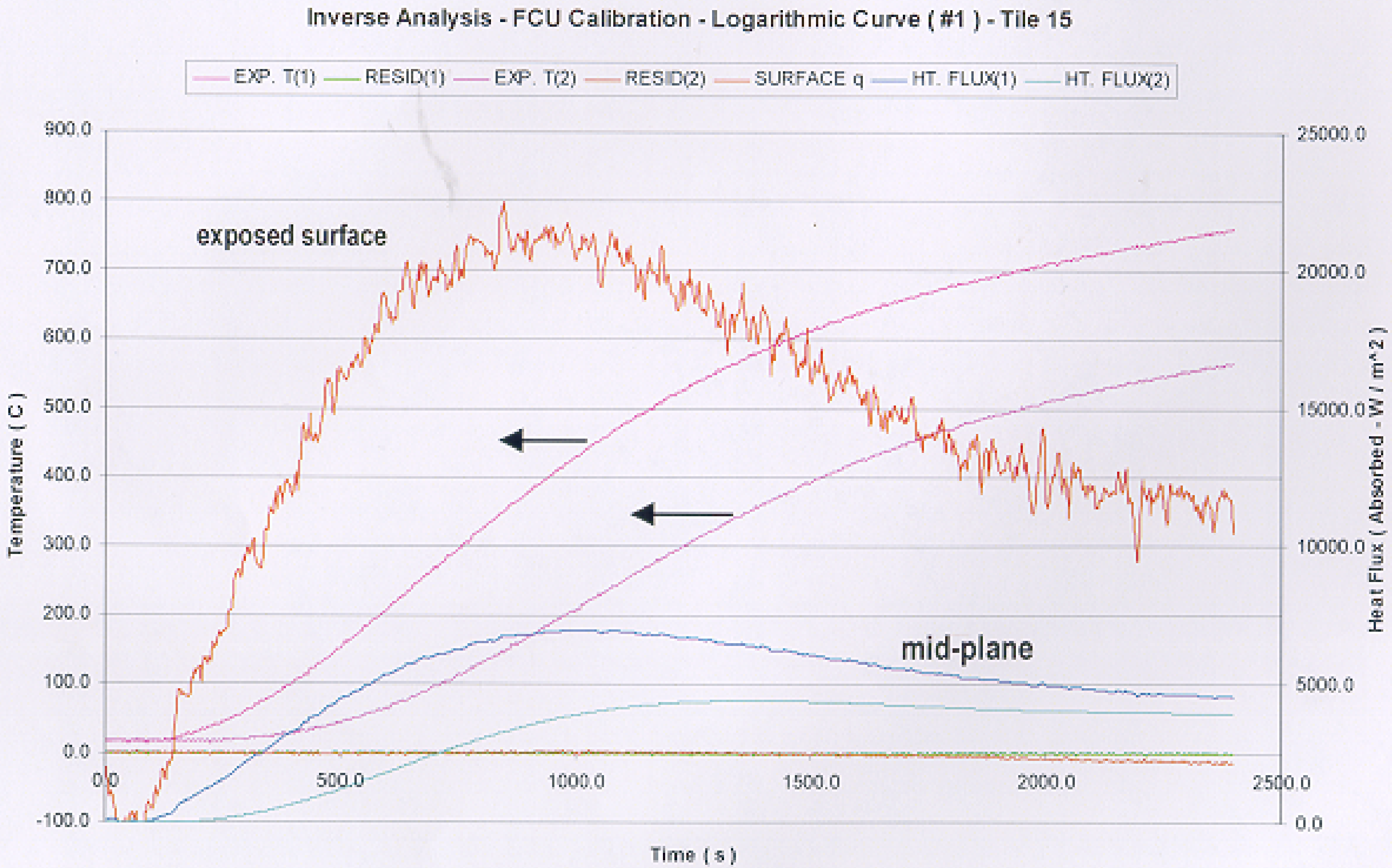

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Calibration Results - Logarithmic Time-Temperature Curve

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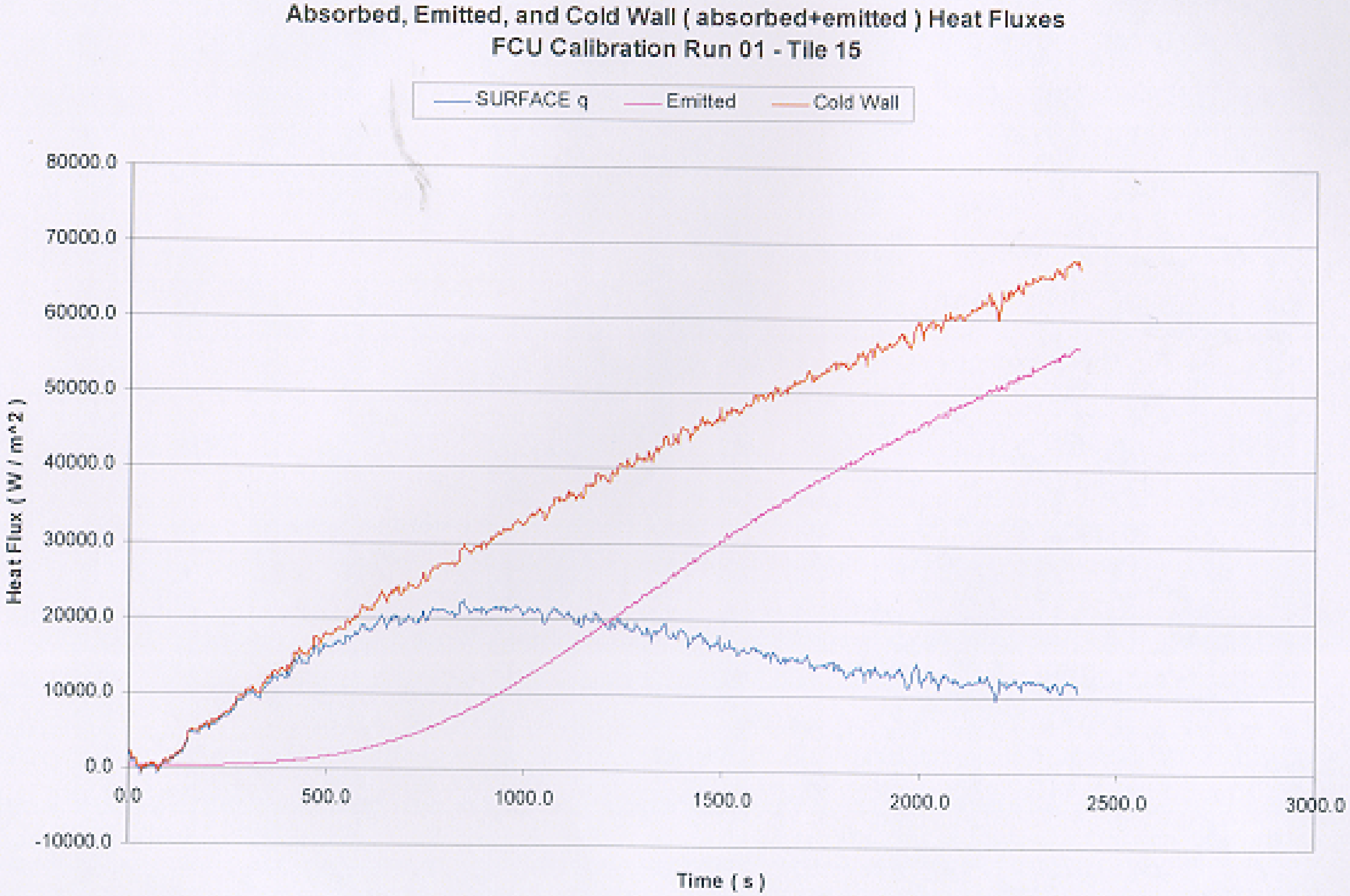

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Summary

- U. S. Coast Guard R & D Center (Groton, CT) has developed a thermal measurement system for characterizing heat transfer in wall furnaces
- One meter square size fits small or full scale furnaces
- Thermal inertia similar to a marine bulkhead
- Operates hot – up to 1000°C
- Monitors furnace temperatures and heat transfer rates
- Redundant heat flux measurements
  - Self calibrating - using a nonlinear parameter estimation code
  - Heat transfer rates - calculated with an inverse heat conduction code

What's Next?

- Increase heat rejection capability to limit backface temperature rise
- Characterize thermal exposure in an actual furnace
- Compare exposure in different furnaces
  - Attempt correlation of furnace temperatures and heat fluxes
  - Use results as an aid in harmonizing exposures

- Adapt technique to intermediate scale tests
  - Intermediate Scale Calorimeter (ASTM)
  - Single Burning Item (Europe)
  - Room-Corner
- Adapt technique to column furnaces